Modeling of Viscous Fluid Flow

Project Number: 96-25

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Purpose

This is a fundamental fluid mechanical study that will model the phenomena of merging fluids which is important for the problem of liquid sintering. We are excited at the prospect of applying such a model to the measurement of the viscosity of highly undercooled liquid metals in the undercooled temperature range where viscosity cannot be measured at the present time. It is anticipated that this project could lead to the development of a space experiment to measure the viscosity of a significantly undercooled amorphous alloy to test various theories of viscosity with a very “fragile” liquid in the region of rapidly changing viscosity.

Background

Viscosity is an important thermophysical property that controls fluid flow in a liquid and is related to diffusion and the reorientational correlation time through the Stokes-Einstein and Debye-Stokes-Einstein relations. Viscosity appears in the classical equations for nucleation and crystal growth by aid of the Stokes-Einstein relation which inversely relates viscosity with the diffusion coefficient. A problem is that viscosity data do not exist between slightly above the glass transition temperature and just below the melting temperature for difficult glass formers because the liquid crystallizes. Over this temperature range the viscosity changes by as much as 10 orders of magnitude or more. Viscosity data can be fit with empirical equations but it is not known if it can be used to predict the viscosity in the undercooled region where viscosity normally cannot be measured. The theoretical viscosity models, used to interpolate between measured viscosity, vary by an order of magnitude and need scientific justification and testing in order to determine which are most suitable for modeling over the entire supercooled range from the melting temperature to glass transition. The results of this study will be used to propose critical measurements of the viscosity of a highly undercooled liquid to test the validity of viscosity theories.

Approach

A computer code will be developed and tested with low-g fluid merging experiments with axial symmetry. Digitized video data will be used to test the computer code.

Accomplishments

The analytical formulation of the coalescence of two liquid masses has been completed. The mathematical model of liquid coalescence, which is based on the conservation of mass and momentum principles for fluid dynamics, was solved numerically for the two-dimensional case. A computer code was developed based on the boundary element method (BEM) which solves the liquid coalescence problem for two circular drops. Figure 54 shows the evolution of the shape as two liquid drops of same diameter merge under the action of surface tension force in the absence of gravity force.

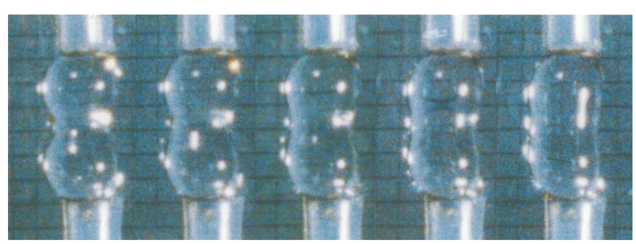

FIGURE 54.—Theoretical plot of the merging of two drops of glycerin.

A set of low-gravity experiments were designed for the purpose of validating the merging results obtained with the numerical fluid dynamics solution developed in the theoretical formulation task. The tests in the experiments comprised of merging together two liquid drops of different diameters, and the merging of a liquid drop with a planar surface. Four different drop diameters were tested: 0.8, 1.0, 1.6, and 2.0 cm; and four different liquids: glycerin, silicone oil A, silicone oil B, and distilled water. The experiments were performed on board the NASA/KC–135 during the week of July 14, 1997, and lasted for 4 days. The merging process was visually recorded using high speed movie camera and film. A film speed of 250 frames/second was used for all of the experiments performed. Also, each merging test was performed during the low gravity portion of the flight parabola which nominally lasted for 20 seconds.

The data were analyzed by measuring the surface deformation during the merging process. The data analysis was facilitated by digitizing the appropriate single frame from the high-speed developed film. Figure 55 shows five single consecutive frames of the evolution of the merging process of two glycerin drops 1-cm diameter each. Figure 96 shows the variation of the contact radius in centimeters with time as two glycerin spheres of equal diameter of 1.0 cm each merge in a low-gravity environment. The continuous curves represent the predictions from the numerical model for different liquid temperatures: 20, 25, 30, 35, and 40 degrees Centigrade respectively. The data points of the measured contact circle diameter from five consecutive frames are plotted in figure 55. The liquid temperature for the measured data shown in figure 56 was approximately 30 to 35 degrees. The figure shows excellent agreement between the low-gravity experiment and the calculated data for glycerin at 30 to 35 degrees.

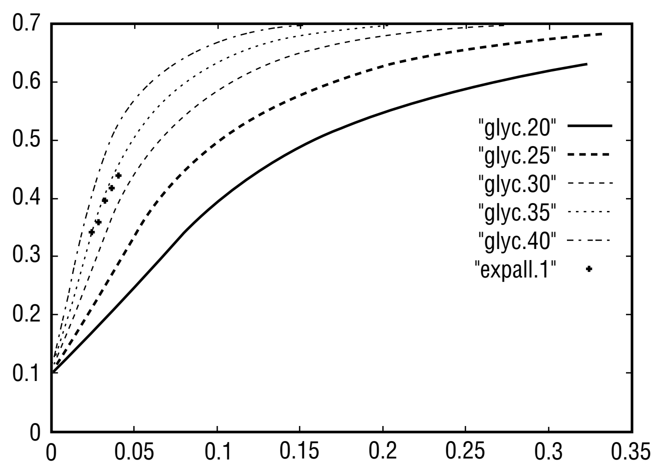

Figure 55.—Images of five consecutive frames from the high speed film of merging glycerin droplets.

Planned Future Work

The BEM numerical code will be further tested and examined for extension to the axialsymmetry case. The second and final KC–135 experimental flights will be compared with the BEM code.

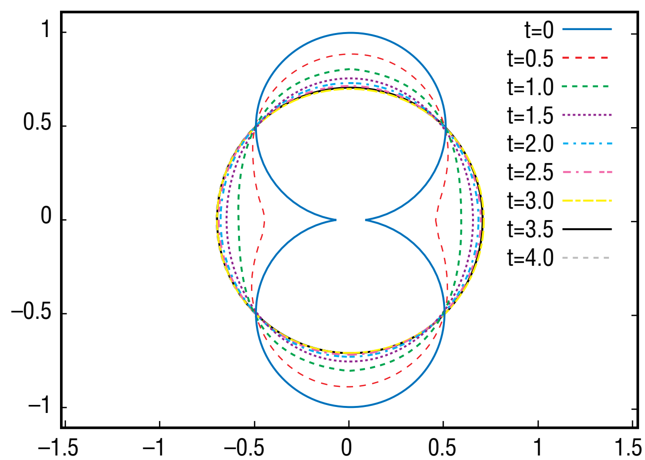

Figure 56.—Normalized neck diameter versus time for glycerin at five temperatures and five data points for experimental data

Publications and Patent Applications

Paper in preparation: “Liquid Drop Coalescence in Microgravity,” for submission to: Microgravity Science and Technology. Also manuscripts on the same subject are being prepared for presentation at the following international conferences:

- 32nd COSPAR Scientific Assembly 40th Anniversary—Nagoya, Japan, 12–19, 1998.
- Joint First Pan-Pacific Basin Workshop and

Fourth Japan/China on Microgravity Sciences, Tokyo, Japan, 8–11, July 1998.

Patent Application to be submitted: "New Method for Determining the Viscosity and Surface Tension of Highly Viscous Liquid Melts."

Funding Summary ($k)

	FY96 and FY97
Authorized:	73
Processed:	71.5
Committed:	61.5
Obligated:	57.8
Costed:	43.7
Credit card lost:	1.6

Status of Investigation

Project approved—October 1995

Funding authorized—March 1996

Estimated completion—June 1998

To be continued in FY97/98 with funds restored to credit card.